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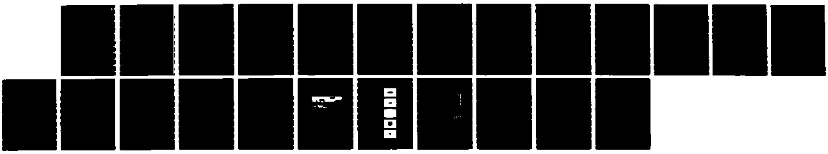

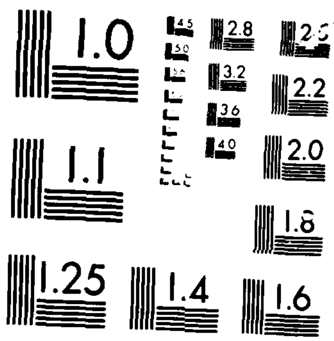

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by

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endel[4], O. H. Bauer[4], H. C. Koons[5] and R. H. Holzw

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ABSTRACT

Plasma waves observed during the March 21, 1985, AMPTE magnetotail barium release are described. Electron plasma oscillations provided local measurements of the plasma density during both the expansion and decay phases. Immediately after the explosion the electron density reached a peak of about 4×10^5 cm^{-3}, and then started decreasing approximately as $t^{-2.4}$ as the cloud expanded. About 6 minutes after the explosion the electron density suddenly began to increase, reached a secondary peak of about 2.4×10^2 cm^{-3}, and then slowly decayed down to the pre-event level over a period of about 15 minutes. The density increase is believed to be caused by the collapse of the ion cloud into the diamagnetic cavity created by the initial expansion. The plasma wave intensities observed during the entire event were quite low. In the diamagnetic cavity electrostatic emissions were observed near the barium ion plasma frequency, and in another band at lower frequencies. A broadband burst of electrostatic noise was also observed at the boundary of the diamagnetic cavity. Except for electron plasma oscillations no significant wave activity was observed outside of the diamagnetic cavity.

INTRODUCTION

This paper describes plasma wave observations during an AMPTE (Active Magnetospheric Particle Tracer Explorers) magnetotail barium release that occurred on March 21, 1985. This release was one of a series of lithium and barium ion releases performed in the solar wind and magnetotail by the AMPTE/IRM (Ion Release Module) spacecraft during the period from September 11, 1984, to July 18, 1985. Results from the solar wind lithium and barium releases have already been described by Gurnett et al. [1985], Häusler et al. [1986] and Gurnett et al. [1986]. Here we report on the initial results from the first magnetotail release.

For the March 21 event two canisters of barium were released from the IRM on the nightside of the earth at a radial distance of 12.0 R_E, a local time of 23.75 hours, and a Z coordinate relative to the neutral sheet, using the Fairfield [1980] model, of $dZ = 0.0\ R_E$. The magnetic field and plasma measurements show that the spacecraft was located in the plasma sheet slightly south of the neutral sheet. The ground magnetometer data were quiet, with magnetic disturbances generally less than about 50 nT. The canisters were exploded simultaneous at 0920:33.4 UT (Universal Time) at a distance estimated to be about 0.9 km from the spacecraft.

PLASMA DENSITY PROFILE

One of the primary objectives of the IRM plasma wave investigation was to measure the density of the injected ion cloud. The plasma density can be determined from two effects: the propagation cutoff of external electromagnetic radiation, and locally generated electron plasma oscillations. Both of these effects can be seen in the top panel of Figure 1 which shows a frequency-time spectrogram of the electric fields during the March 21 event. For comparison the bottom panel shows the magnetic field at the IRM. A fraction of a second after the explosion, at about 0920:34, an abrupt decrease can be seen in all the wave intensities. The magnetic field also abruptly goes to zero as the diamagnetic cavity formed by the highly conducting cloud sweeps over the spacecraft. The decrease in the wave intensities is caused by the high plasma density which blocks the galactic and terrestrial radio emissions at all frequencies below the electron plasma frequency. Shortly after the arrival of the ion cloud a narrowband emission can be seen sweeping downward in frequency, starting at about 3 MHz. This emission is caused by electron plasma oscillations at the electron plasma frequency, $f_{pe} = 9\sqrt{N_e}$ kHz, where N_e is the electron density in cm^{-3}. Because the plasma frequency depends only on the electron density, the oscillation frequency provides a direct measurement of the local electron density. An electron density scale is given on the right-hand side of Figure 1.

The electron density varies over a large range, from a peak of about 4×10^5 cm^{-3} a few seconds after the explosion, to below 1 cm^{-3} about 20 minutes after the explosion. The ambient density before the explosion is estimated to be about 4 to 6 cm^{-3}. Two distinct phases can be identified in the electron density variations. For the first 6 minutes, from about 0920:34 to 0926:40, the density decreases monotonically, varying approximately as $t^{-2.4}$, where t is the time from the explosion. The spectrogram in Figure 1 shows that the propagation cutoff of the external galatic radio noise is about a factor of two above the local electron plasma frequency. This difference between the propagation cutoff and the local plasma frequency indicates that the IRM is located inside a dense expanding shell of plasma. A similar shell-like density configuration was observed during the AMPTE solar wind barium release [Gurnett et al., 1985]. At 0926:40 the electron density profile undergoes a qualitative change. The density abruptly starts to increase, reaches a secondary peak of about 2.4×10^2 cm^{-3} at 0928, and then continues to decrease, eventually dropping below 1 cm^{-3} at about 0940. The density increase corresponds almost exactly with the return of the magnetic field.

COMPARISONS WITH GROUND PHOTOGRAPHS

To understand the significance of the plasma density variations, it is useful to compare the IRM density measurements with ground-based photographs. Figure 2 shows a series of photographs of the ion cloud taken from White Sands, NM, [Bernhardt et al., 1986]. The times of these photographs are indicated at the top of Figure 1 and are labeled A through E. Photographs A, B and C show that the cloud is undergoing a more-or-less radial expansion. The IRM is near the center of the cloud. By the time of photograph C, which was taken near maximum expansion, striations have started to develop along the outer boundary of the cloud. The shell-like structure is also clearly evident. The diameter of the cloud at this time is about 300 km. In photograph D, the radial expansion has ceased and the cloud has developed an elongated shape. The axis of the cloud is aligned along the magnetic field, which in the geomagnetic tail is nearly along the line of sight. By the time of photograph E, which has been intensified to compensate for the decreasing brightness, the IRM has moved outside the cloud.

Comparisons of Figures 1 and 2 show that the smooth monotonic $t^{-2.4}$ density decrease before 0926:40 is associated with the expansion phase. The density increase at 0926:40, which occurs at the transition from a spherical to an elongated shape, is believed to be caused by the collapse of the dense shell-like outer envelope into the diamagnetic cavity. Subsequent variations are probably caused mainly by the convection of the cloud away from the IRM.

WAVES IN THE DIAMAGNETIC CAVITY

The plasma waves observed during the March 21 release are summarized in Figure 3. The intensity scale for each of the 16 channels is logarithmic and covers a dynamic range of 106 db, from 0.5 μVolts/m to 100 mVolts/m. The waves in the diamagnetic cavity are very similar to the December 27, 1984, solar wind barium release [Gurnett et al., 1985]. Two narrowband emissions can be seen sweeping downward in frequency with increasing time. The upper band starts at about 3 kHz a few seconds after the explosion and sweeps down to about 100 Hz. This band is centered almost exactly on the barium ion plasma frequency, f_{pBa^+}, which is indicated by the dashed line. The barium ion plasma frequency is given by dividing the electron plasma frequency by the square root of the ion to electron mass ratio, which for barium ions is $\sqrt{m_{Ba}/m_e} = 501$. The lower band is about a factor of ten below the barium ion plasma frequency. This band is very weak and difficult to identify. It starts a few seconds after the explosion at about 311 Hz and within 1 minute has dropped below 100 Hz.

Further details of the narrowband emissions are given in Figure 4, which shows high resolution spectrograms of the wideband waveform data obtained during the event. The upper band starts in the 0 to 10 kHz channel, and then shifts into the 0 to 1 kHz channel about 1 1/2 minutes after the onset. The bandwidth of the emission is very narrow,

$\Delta f/f \sim 10\%$, and is centered almost exactly on the barium ion plasma frequency. Toward the end of the event, two additional bands can be seen at harmonics of the main emission. These harmonic effects are probably produced by nonlinear distortion in the wideband data system. The emission also has considerable fine structure. The fine structure shows a strong modulation at twice the spacecraft rotation rate (spin period, 4.5 seconds), with the maximum intensities occurring when the antenna axis is oriented parallel to the spacecraft-sun line. A representative electric field spectrum is shown in Figure 5 at 0922:48. This spectrum assumes that the wavelength is longer than the antenna. The electric field strength integrated over the entire band is about 10 μVolts/m.

The lower band can be best seen in the 0 to 1 kHz spectrogram of Figure 4 for about 1 minute after the explosion. This emission has a relatively broad bandwidth, $\Delta f/f \sim 50\%$, and is not associated with any known characteristic frequency of the plasma. The frequency decreases rapidly with increasing time, proportional to f_{pBa^+}, but about a factor of ten lower. The lower band also shows clear evidence of spin modulation and tends to reach peak intensity when the antenna axis is parallel to the spacecraft-sun line. The field strength of the lower band is about 3 μVolts/m.

At present the detailed origin of these emissions remains unknown. Because of the close relationship to the ion plasma frequency it seems almost certain that the upper band is an ion acoustic wave. Studies of similar waves observed during the first solar wind barium release [Gurnett et al., 1986] provide strong evidence that these waves have

wavelengths much shorter than the antenna. In the solar wind, solar wind protons streaming through the cloud provide a possible free energy source to drive these waves. However, no similar free energy source exists in the magnetotail, except possibly for a small (~ 10 km/sec) drift relative to the plasma sheet. The absence of a suitable free energy source suggests that it may be necessary to consider an interaction between the spacecraft and the ion cloud to explain the origin of these waves.

WAVES AT THE CAVITY BOUNDARY

The 16-channel plot in Figure 3 shows that an abrupt broadband burst of noise occurs at both the entry, 0920:34, and exit, 0926:40, of the diamagnetic cavity. The entry burst is very sharp and impulsive, lasting less than 1 second, and the exit burst is much broader, lasting about 15 seconds. The electric field spectrums at the entry and exit, shown in Figure 5, are quite different. The entry spectrum extends to higher frequencies and is much flatter than the exit spectrum. These differences are probably due to differences in the boundary speed relative to the spacecraft, which is ~ few km/s for the entry and probably only a few hundred m/s for the exit, and to the increase in the boundary thickness as the cloud expands. Although the shape of the spectrum is different at the entry and exit, the broadband field strength, integrated over all frequencies, is similar, about 1 mVolt/m.

The location of these bursts strongly suggests that the noise is driven by the electron magnetization current that flows along the boundary of the diamagnetic cavity. Most likely the noise is caused by a current-driven ion-acoustic instability [Krall and Trivelpiece, 1973]. For the large electron to ion temperature ratios, $T_e/T_i \sim 5$, believed to exist in the cloud, the threshold electron drift velocity for the ion acoustic instability is quite low, much less than the estimated electron drift velocity at the cavity boundary.

WAVES OUTSIDE THE DIAMAGNETIC CAVITY

As can be seen from Figure 3, the wave intensities outside the diamagnetic cavity are very low. This result is in sharp contrast to the AMPTE solar wind releases [Gurnett et al., 1985; Häusler et al., 1986; Gurnett et al., 1986] which were characterized by very intense broadband electrostatic and electromagnetic noise upstream of the ion cloud. The absence of any comparable noise during the magnetotail release confirms that this upstream noise was caused by an interaction with the solar wind.

The only noise present outside of the diamagnetic cavity are some very weak broadband electrostatic emissions below about 5 kHz (see Figure 3, from 0939 to 0944), and electron plasma oscillations from about 17.8 to 100 kHz. The broadband emissions are not believed to be associated with the ion cloud because similar emissions were also present before the explosion. Broadband electrostatic noise of this type is a common feature of the distant magnetotail [Gurnett et al., 1976]. The electron plasma oscillations are qualitatively similar to the plasma oscillations observed inside the diamagnetic cavity. At present the mechanism responsible for the electron plasma oscillations is not known. Two types of plasma oscillations occur, relatively smooth steady emissions, such as before about 0932, and more intense impulsive emissions such as after 0932. The smooth emissions are

probably thermally excited electron plasma oscillations of the type studied by Hoang et al. [1980], and the impulsive emissions are probably instabilities driven by electron beams or other nonthermal processes.

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REFERENCES

Bernhardt, P. A., et al., Observations and theory of the AMPTE magnetotail barium releases, J. Geophys. Res., in preparation, 1986.

Fairfield, D. H., A statistical determination of the shape and position of the geomagnetic neutral sheet, J. Geophys. Res., 85, 775, 1980.

Gurnett, D. A., et al., Plasma waves associated with the AMPTE artificial comet, Geophys. Res. Lett., 12, 851, 1985.

Gurnett, D. A., et al., Waves and electric fields associated with the first AMPTE artificial comet, J. Geophys. Res., accepted, 1986.

Gurnett, D. A., L. A. Frank and R. P. Lepping, Plasma waves in the distant magnetotail, J. Geophys. Res., 81, 6059, 1976.

Gurnett, D. A., et al., Analysis and interpretation of the shock-like electrostatic noise observed during the AMPTE solar wind lithium releases, J. Geophys. Res., 91, 1301, 1986.

Häusler, B., et al., Plasma waves observed by the IRM and UKS spacecraft during the AMPTE solar wind lithium releases: Overview, J. Geophys. Res., 91, 1283, 1986.

Krall, N. A., and A. W. Trivelpiece, Principles of Plasma Physics, McGraw-Hill, N. York, 9, 1973.

Hoang, S., J.-L. Steinberg, G. Epstein and P. Tilloles, The low-frequency continuum as observed in the solar wind from ISEE 3: Thermal electrostatic noise, J. Geophys. Res., 85, 3419, 1980.

FIGURE CAPTIONS

Fig. 1. A frequency-time spectrogram of the plasma wave electric fields observed during the magnetotail barium release on March 21, 1985. The ion cloud formed by the explosion blocked the galactic and terrestrial radio noise and produced the depressed noise levels evident after 0920:34. The electron plasma oscillations give the local electron density, as indicated by the scale on the right-hand side of the plot.

Fig. 2. A series of photographs showing the expansion and subsequent evolution of the ion cloud formed by the March 21 magnetotail release. The IRM is initially located at the center of the cloud. However, by photograph E the spacecraft (indicated by the asterisk) has moved outside of the cloud.

Fig. 3. A 16-channel plot of the electric field intensities during the March 21 event.

Fig. 4. High resolution spectrograms showing details of the two low frequency emission bands observed in the diamagnetic cavity.

Fig. 5. Selected electric field spectrums of the emission at f_{pBa^+}, and the noise bursts at the entrance and exit of the diamagnetic cavity.

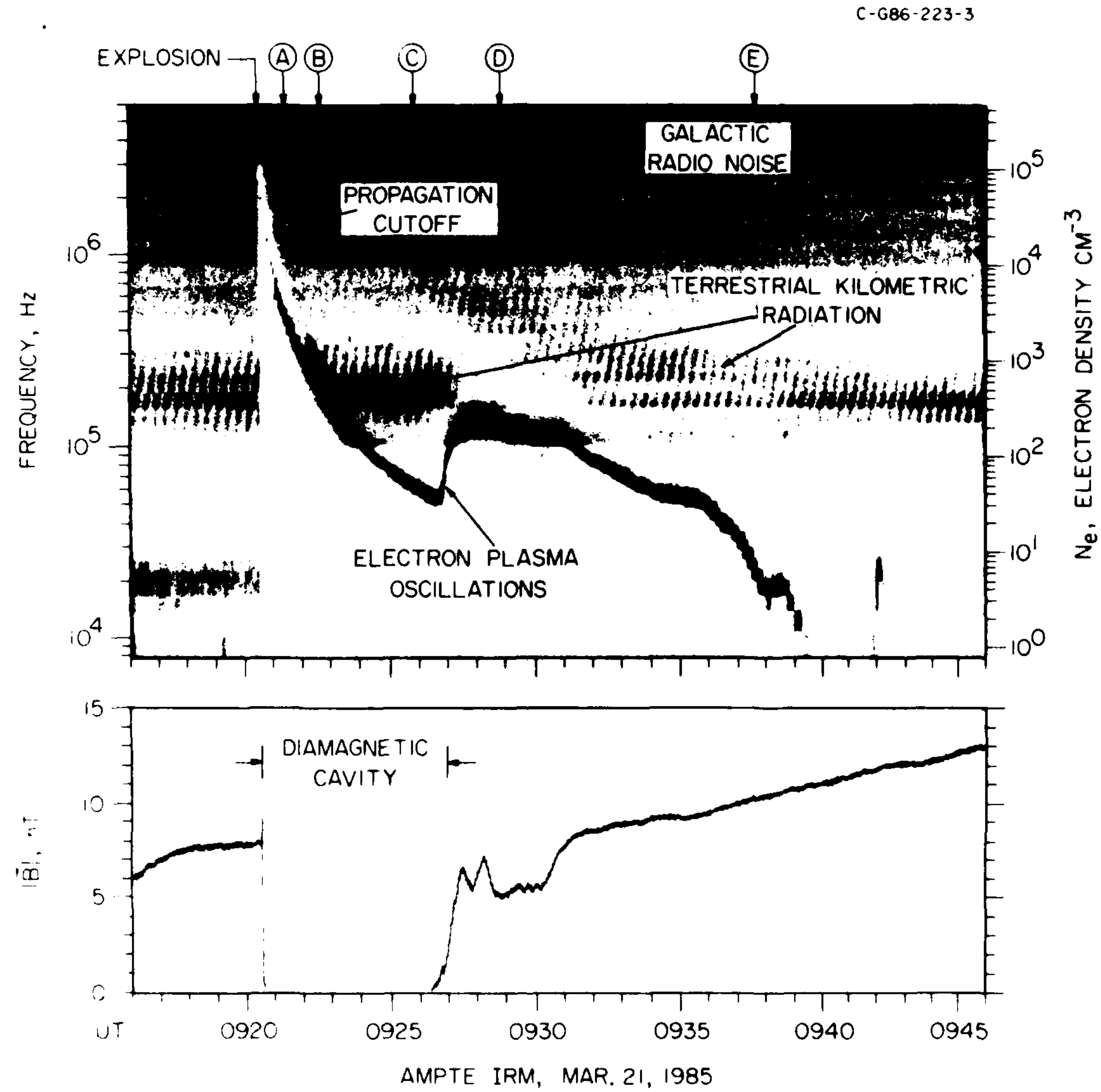
C-G86-223-3
EXPLOSION
A
B
C
D
E
GALACTIC RADIO NOISE
PROPAGATION CUTOFF
TERRESTRIAL KILOMETRIC RADIATION
ELECTRON PLASMA OSCILLATIONS
FREQUENCY, Hz
Ne, ELECTRON DENSITY CM-3
DIAMAGNETIC CAVITY
UT
0920
0925
0930
0935
0940
0945
AMPTE IRM, MAR. 21, 1985

Figure 1

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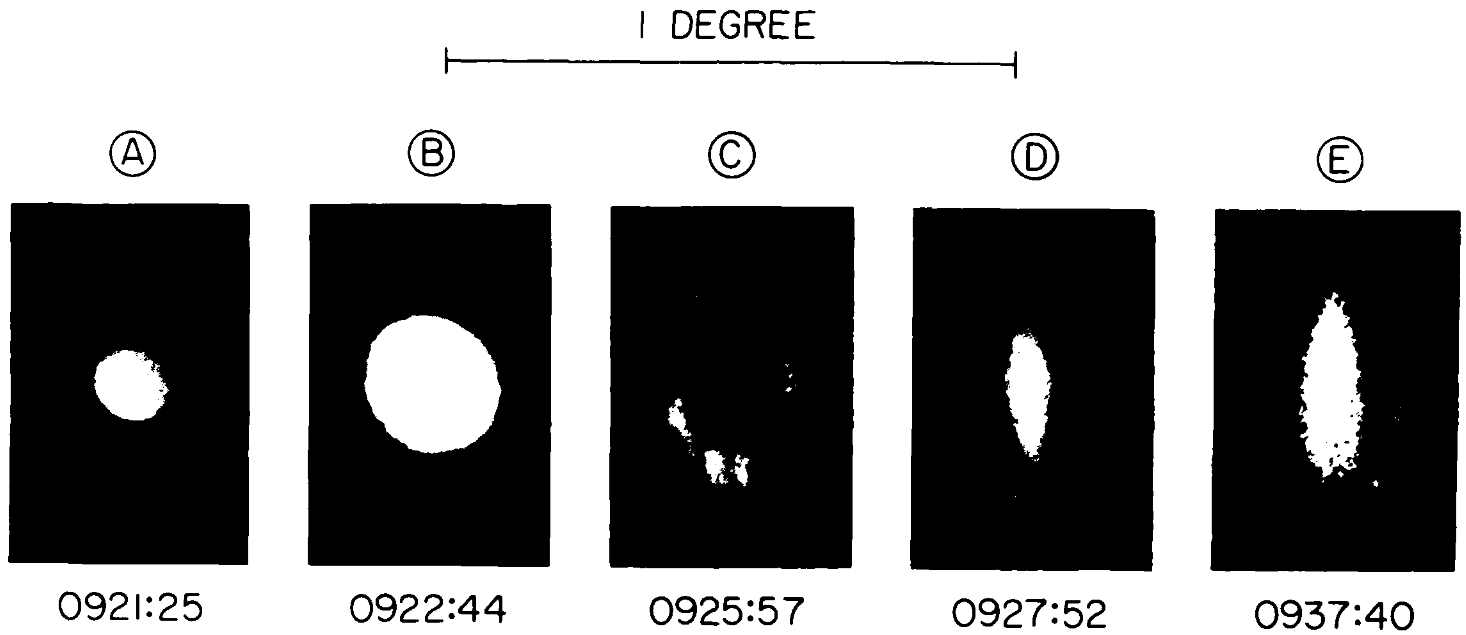

Figure 2

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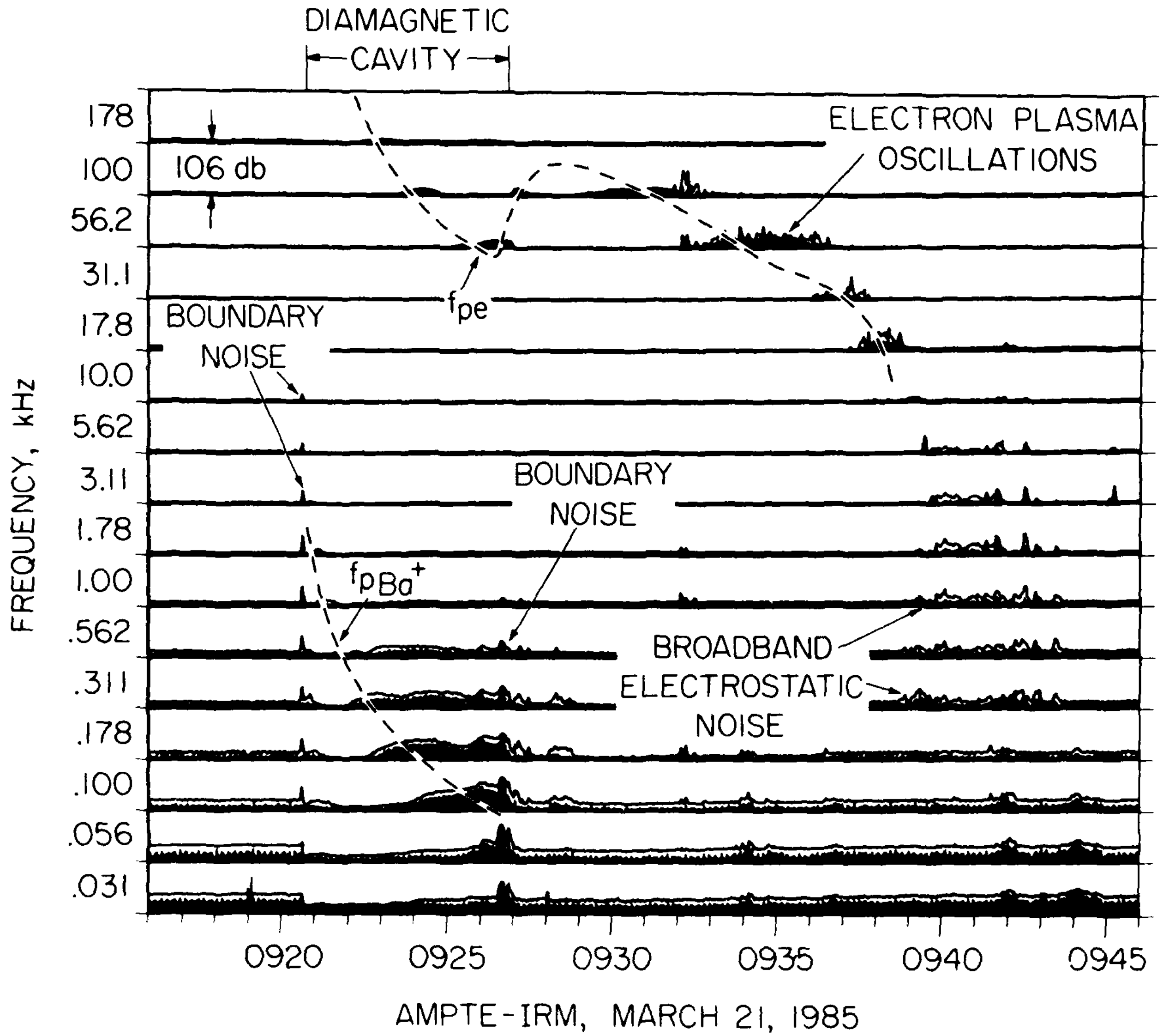

Figure 3

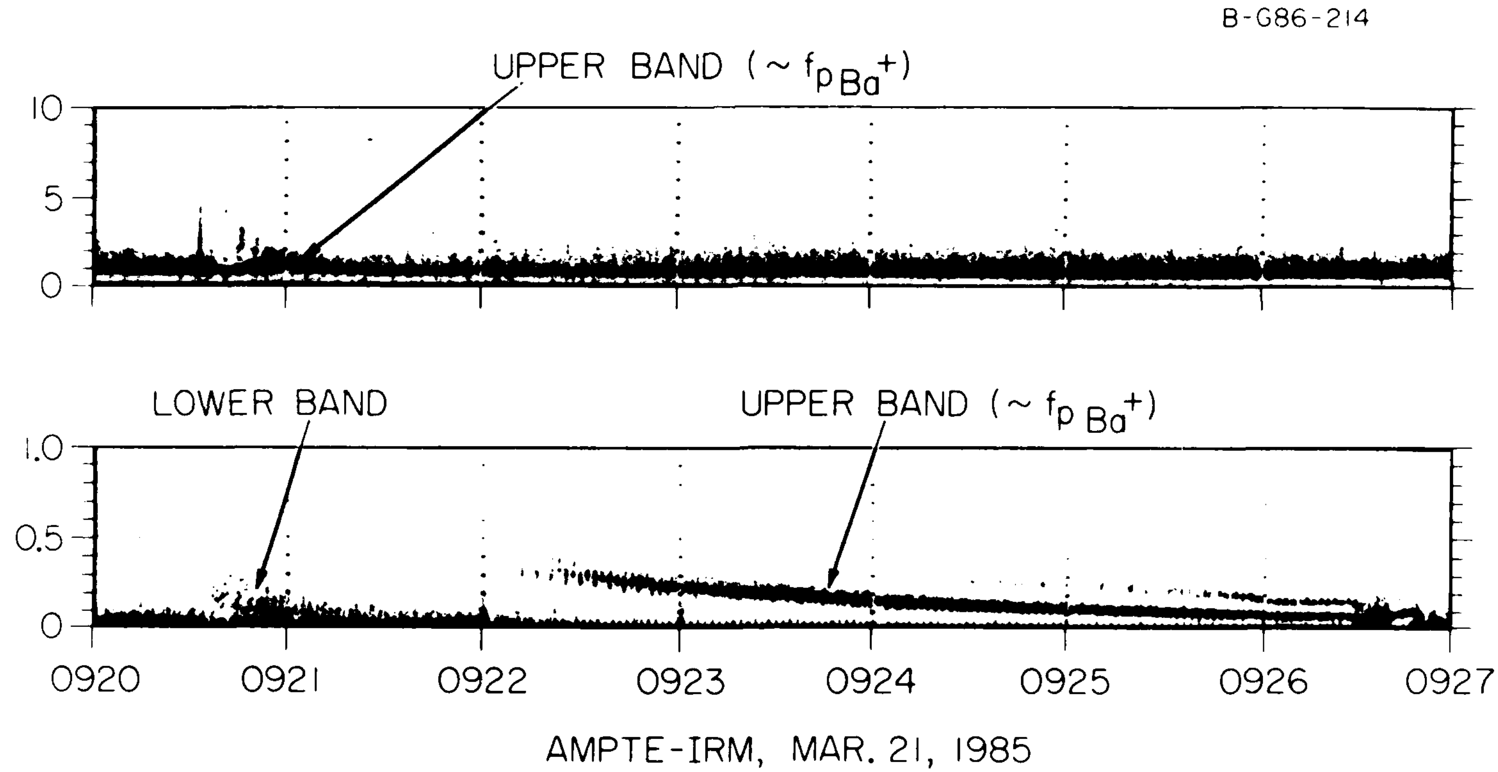
B-G86-214
UPPER BAND (~ $f_{p\,Ba^+}$)
10
5
0
LOWER BAND
UPPER BAND (~ $f_{p\,Ba^+}$)
1.0
0.5
0
0920
0921
0922
0923
0924
0925
0926
0927
AMPTE-IRM, MAR. 21, 1985

Figure 4

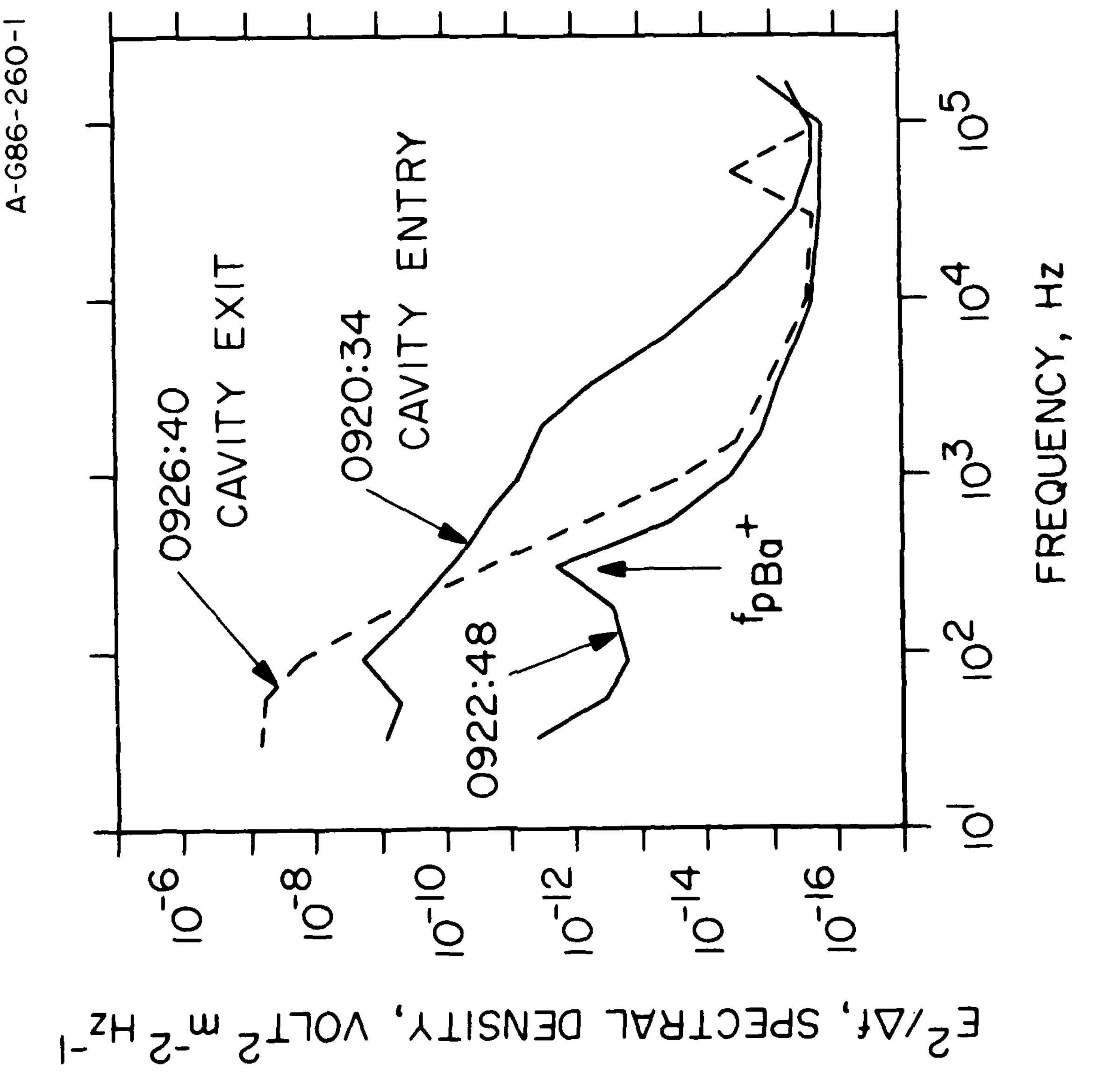
A-G86-260-1
0926:40
CAVITY EXIT
0920:34
CAVITY ENTRY
0922:48
f_{pBa^+}
10^1
10^2
10^3
10^4
10^5
FREQUENCY, Hz
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{-14}
10^{-16}
$E^2/\Delta f$, SPECTRAL DENSITY, $VOLT^2\ m^{-2}\ Hz^{-1}$

Figure 5

END

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